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SPECIFIC GRAVITY STUDIES OF ILLINOIS COAL

BY
MERLE L. NEBEL

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BULLETIN No. 89 JULY, 1916

SPECIFIC GRAVITY STUDIES OF ILLINOIS COAL.

BY MERLE L. NEBEL,
RESEARCH FELLOW IN ENGINEERING EXPERIMENT STATION.

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SPECIFIC GRAVITY STUDIES OF ILLINOIS COAL

I. Introduction.

The specific gravity of coal, especially of high moisture bituminous coal, such as is found in Illinois, is not a fixed value. Coals of different types may have characteristically different specific gravities, and it is equally true that coals of the same type vary greatly in specific gravity.

The object of this bulletin is to present the results of a study of (1) the effect of moisture upon the specific gravity of coal, and (2) the methods of determining the specific gravity of coal. The commercial aspects of the problem are discussed, and values are given for the specific gravity of coal from many of the mining districts of the State of Illinois. The specific gravity of bright and dull coal is also considered.

The investigation was carried on under the direction of Professor H. H. Stoek of the University of Illinois, who suggested the problem and whose advice and criticism were of great value. Experiments were conducted in the laboratories of the Department of Mining Engineering of the University of Illinois, and field trips were made to the Vermilion county coal field, where samples of coal were collected from a number of mines. Other samples were obtained from various sources. The author is indebted to Professor E. A. Holbrook of the Department of Mining Engineering of the University of Illinois for assistance in securing samples of coal and for valuable suggestions and criticisms during the progress of the work; and also to Professor S. W. Parr of the Department of Chemistry of the University of Illinois, and Mr. Fred H. Kay, of the Illinois State Geological Survey, for advice.

II. Specific Gravity of Coal as Affected by Its Ash and Moisture Contents.

The chief factors which affect the specific gravity of coal, aside from difference in type, are (a) the amount of impurities, and (b) the amount of moisture present in the coal. A high-ash coal has a greater

specific gravity than a low-ash coal of the same type. In general, a wet coal has been found to have a greater specific gravity than a dry coal of the same type. However, the effect of moisture in varying proportions upon the specific gravity of coal is more or less complicated, and it is chiefly with this phase of the subject that the present bulletin deals. Though the effect of ash content has long been recognized, apparently very little study has been made of specific gravity under varying conditions of moisture content. This is probably because most of the coals of Europe and of the eastern United States which have been studied have a low moisture content, seldom over 3 or 4 per cent; whereas the coals of the Middle West may contain moisture as high as 15 or 20 per cent.

The ordinary method of determining the specific gravity of a solid, such as coal, is to weigh it in air, then immerse it in water and weigh it again, the specific gravity being equal to the ratio of the weight in air to the loss of weight in water. However, since coal is porous, probably most of the contained moisture is held mechanically in its pores. When coal is dried the moisture leaves the pores, which become filled with air; if the dry coal is placed in water, the air in the pores is displaced by the water, and the coal becomes saturated. Under such circumstances the length of time coal is immersed in water before it is weighed affects materially the value obtained for the specific gravity.

As early as 1892 Eckley B. Coxe recognized the effect of ash upon the specific gravity of coal. In his laboratory at Drifton, Pennsylvania, in which analyses of coal were made and boiler tests run, he required specific gravity determinations to be made of all coal samples. In his Presidential Address before the New England Cotton Manufacturers' Association in 1893, he said, "There seems to be no doubt that there is a close relation between the specific gravity of coal and its percentage of ash. . . . A careful study of a great number of analyses of coal and determinations of specific gravity has led us to believe that, although our experiments are not as yet absolutely conclusive, there is a strong probability that, for a given size of coal from the same colliery under ordinary circumstances, the determination of the specific gravity of an average sample will give very nearly the same percentage of ash as will be determined by analysis, although the relation may not be exactly the same for different mines or for different sizes of coal.

"If the specific gravity and percentage of ash, in any sample of coal below egg size, are known, the percentage of ash in any other sample of the same coal, and from the same colliery, can be satisfactorily de-

termined (we are inclined to think) from the specific gravity of that sample by the following formula:

$y' = y + (x' - x)a$, in which
x = the standard specific gravity,
y = the standard percentage of ash,
x' = the specific gravity of coal determined by our apparatus,
y' = the percentage of ash to be determined,
a' = a constant for coal from same mine.

"In the Lehigh region, for any size of coal, we find that, within what may be called the commercial limit of purity, an increase of 0.01 in the specific gravity corresponds to about the increase of 1½ per cent of ash; that is to say, that if coal of the specific gravity of 1.54 contained 8 per cent of ash, the same size of coal from the same mine when its specific gravity was 1.56 would contain twice 1½ per cent more ash, or 11 per cent."

Mr. Coxe evidently neglected the effect of moisture upon the specific gravity. This effect would not be great, however, in the case of the low-moisture anthracite with which he was chiefly concerned. M. S. Hachita* has suggested that if ordinary coal be considered a mixture of impurities with a pure coal substance, then the specific gravity of the mixture is equal to the sum of the specific gravities of each component multiplied by its percentage of the total mixture: that is,

$100\ gm = gpx + gi\ (100 - x)$, in which
gm = specific gravity of the mixture,
gp = specific gravity of the pure coal,
gi = specific gravity of the impurities,
x = per cent of pure coal in mixture,
$100 - x$ = per cent of impurities.

"Float and sink" tests of coal are very commonly made to determine the relation between the coal and the shale and other impurities which are mixed with it, and to study the possibilities of clean separation. Among the earliest of such tests in this country were those of Eckley B. Coxe, made in connection with the work on specific gravity previously referred to. The method in general use today is essentially the same as that used by him twenty-five years ago.

About 1910 the Department of Mines of Canada conducted an investigation of Canadian coals, including float and sink tests. Dr. J. B.

*Eng. and Min. Jour., Vol. 83, pp. 670-73.

Porter, who was in charge of the work, states that the specific gravity of pure bituminous coal is from 1.28 to 1.37.*

The Technologic Branch of the United States Geological Survey (now the United States Bureau of Mines), at the St. Louis Fuel Testing Plant in 1904, carried on float and sink tests, and with a Nicholson hydrometer determined the specific gravity of eighty-two samples of coal. The average value obtained for clean coal was 1.29 and for "average coal" was 1.34.†

III. Terminology of Specific Gravity.

The United States Bureau of Mines, recognizing that coal is a porous substance and that the pores of the coal may contain air or moisture or both, most of which can be easily removed, takes this factor into account by determining two values for the specific gravity; (a) the "apparent" and (b) the "true" or "real." These terms are defined as follows:‡

The "apparent" specific gravity is the specific gravity of the coal including the moisture or air contained in its pores. In determining this value no correction is made for moisture content, and care is taken that no air escapes from the pores during the weighing of the coal in water.

The "true" or "real" specific gravity is the specific gravity of the actual coal substance corrected for air and moisture content. In determining this value the weight of the moisture present is deducted from the weight of the coal and all air is removed from the pores of the coal before it is weighed in water. The methods employed by the Bureau in determining this value are described on page 38.

The true specific gravity of coal, as thus defined, may be compared to a coal analysis calculated to the "moisture-free" or "dry" basis. The true specific gravity is then merely the apparent specific gravity calculated to the dry basis.

Coal analyses are calculated to a dry basis because the moisture content of a given coal may vary greatly with differences in the atmospheric conditions to which it has been exposed. It is often desirable to compare analyses with respect to the thermal or other qualities of the coal, and in order to make such comparison accurate, the error introduced

*J. B. Porter and R. J. Durley, "An Investigation of the Coals of Canada," Vol. 1, p. 165, 1912.

†Bul. 323, U. S. Geological Survey.

‡Private communication from Dr. A. C. Fieldner, Chemist, U. S. Bureau of Mines.

by the variable moisture content must be excluded by calculating to the dry basis.

In order to obtain the true specific gravity it is necessary to know the moisture content of the coal; the specific gravity may then be calculated by the formula:

$$\text{Sp. Gr.} = \frac{W-W_m}{(W-W_m)-W'}, \text{ in which}$$

W = weight in air,
W' = weight in water,
m = percent of moisture.

Since W_m is equal to the weight of moisture present in a lump of coal of weight W, $(W-W_m)$ equals the weight of the actual coal substance excluding the moisture, and $(W-W_m)-W'$ equals the weight of the actual coal substance in water.

In Table I values of the true and apparent specific gravity of the same samples are compared for different contents of moisture. The true specific gravity is greater, a difference of from 0.10 to 0.21 being recorded.

TABLE 1.

TRUE AND APPARENT SPECIFIC GRAVITY FOR DIFFERENT MOISTURE CONTENT.

Sample No.	Moisture Per Cent.	Specific Gravity		Moisture Per Cent	Specific Gravity	
		Apparent	True		Apparent	True
138	4.04	1.23	1.35	4.91	1.26	1.38
141	3.30	1.25	1.35	5.06	1.23	1.37
144	3.07	1.24	1.34	5.64	1.24	1.34
147	3.26	1.24	1.40	5.55	1.22	1.40
150	3.79	1.22	1.38	5.01	1.15	1.36
154	4.85	1.21	1.34	5.48	1.24	1.36
156	4.51	1.24	1.37	4.94	1.22	1.36
159	4.31	1.21	1.35	4.62	1.26	1.38

The term "true" or "real" specific gravity is a rather unfortunate one, since its use implies that any other value for the specific gravity would be unreal or untrue. Such is not the case. Other values are as distinctly true or real as the value so termed, and each has a practical use, which may be even more important than that of the so-called true specific gravity. For this reason it is proposed that in this bulletin the term be replaced by the more logical term "dry specific gravity," which

is directly analogous to the "dry" values of fixed carbon, ash, or B. t. u., given in proximate analyses of coal.

In order to arrive at a more accurate basis for the comparison of the thermal quality of coals of the Illinois type, the idea of recalculation of analyses has been carried still further, and the "ash and moisture-free" or "unit-coal" basis has been developed by Parr.* To this end the effect of all of the impurities—the ash and sulphur, as well as the moisture—has been taken into account, and Parr has shown that the unit B. t. u., determined by such a calculation, is remarkably constant for the coal from a given bed over a considerable area.

Since the "unit-coal" basis of comparing analyses has been found so useful, and since the impurities in the coal affect its specific gravity as well as its other properties, the analogy might be carried still further and a "moisture-free" and "ash-free" or a "unit-coal" basis might be used for specific gravities. The specific gravity on such a basis would be called the "unit-coal" or simply "unit" specific gravity. Such a value might prove of considerable practical utility in comparing coals.

Since there is no term referring to proximate analyses of coal which corresponds to the term "apparent" specific gravity, and since it fills a very definite place, the term will be retained to designate the specific gravity of coal without any correction being made for variation in moisture or ash content.

The term "fresh" specific gravity is proposed to correspond to the "fresh" or "as-received" values of coal analyses. It designates the apparent specific gravity of the coal in its fresh condition; that is, in the condition in which it exists in the ground—saturated with moisture. It is a form of the apparent specific gravity, but it has a very distinct usage and is worthy of a distinct name.

Values of the true and fresh specific gravities of the same samples are compared in Table 2. In this case the true specific gravity is the greater by an amount varying from 0.02 to 0.07. The amount of variation in either case depends upon the moisture content of the coal.

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*Bul. No. 16, Ill. State Geol. Survey, 1909, p. 212.
Bul. No. 29, Ill. State Geol. Survey, 1914, p. 40.

TABLE 2.
COMPARISON OF TRUE AND FRESH SPECIFIC GRAVITY.

Sample No.	Moisture Per Cent	Specific Gravity	
		Fresh	True
125	8.37	1.24	1.27
126	10.24	1.29	1.34
127	9.10	1.29	1.33
128	7.93	1.30	1.32
129	9.04	1.26	1.29
130	7.75	1.28	1.30
131	8.27	1.28	1.32
132	6.79	1.32	1.34
133	7.58	1.26	1.29
134	9.00	1.29	1.32
135	9.13	1.32	1.35
136	8.61	1.26	1.29
137	7.51	1.30	1.33
138	13.58	1.31	1.38
139	15.07	1.27	1.33
140	15.08	1.29	1.36
141	13.64	1.30	1.37
142	14.62	1.28	1.35
144	12.65	1.28	1.31
145	14.57	1.28	1.35
146	13.85	1.28	1.35
147	14.95	1.27	1.34
148	15.02	1.32	1.39
149	14.10	1.29	1.36
150	13.67	1.32	1.39
151	13.40	1.27	1.33
152	13.91	1.30	1.36
153	13.40	1.29	1.35
154	14.72	1.30	1.34
155	14.13	1.31	1.38
156	13.30	1.31	1.37
157	14.30	1.31	1.37
158	13.21	1.29	1.35
159	14.21	1.31	1.38
160	14.46	1.30	1.37
161	13.83	1.30	1.37

IV. LABORATORY STUDY OF SPECIFIC GRAVITY OF COAL.

After trying out a number of the well known methods of determining specific gravity, such as the hydrometer, pyncnometer, and Jolly Balance, it was agreed that the Jolly Balance was the form of apparatus best adapted for carrying on the investigations contemplated in the present research. A discussion of the experiments carried out and a description of the various forms of apparatus used for determining specific gravity will be found in Appendix 1.

1. *Specific Gravity of Air-Dry Coal.*—In studying the specific gravity of air-dry coal it is necessary that all air be removed from the pores of the coal. The chemists of the United States Bureau of Mines accomplish this by boiling the coal about three hours under a partial vacuum obtained by the use of an aspirator.

When determining the specific gravity of air-dry coal by the Jolly Balance method, it was noted that very soon after the lumps were immersed in water, usually within a minute, bubbles of air began to rise through the water and that air continued to be given off for several hours. Two series of experiments were conducted to study (a) the effect of this expulsion of air on the specific gravity, and (b) the length of time required for the removal of all the air.

Experiment (a)—In the first experiment to determine the effect on specific gravity of expulsion of air the apparent specific gravity was determined for seventeen lumps from the same sample of coal, lumps which represented the average of the sample being selected. The lumps were immersed in water at room temperature for three days, and their weights in water were determined at the end of 1, 2, 3, 4, 5, 15, 20, 24, 48 and 72 hours. The specific gravity was determined in each case from the formula:

$$\text{Sp. Gr.} = \frac{Wa}{Wa - W}, \text{ in which}$$

$Wa =$ weight in air,

$W =$ weight in water.

The results are shown graphically by the curve in Fig. 1, which represents the average of the seventeen samples immersed for a period of 24 hours. The specific gravity increased in value as the air was expelled.

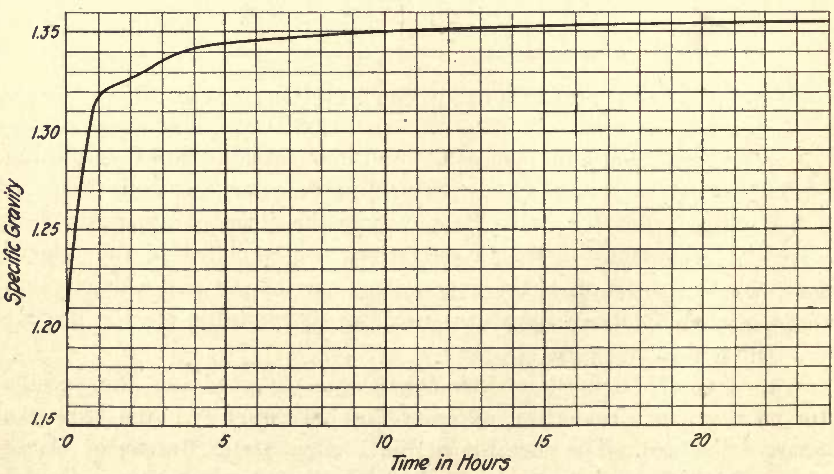

Fig. 1. Graph Showing Effect on Specific Gravity of Immersing Coal in Water Twenty-four Hours, Average of Seventeen Tests.

No appreciable change was noted after 15 hours, but by the end of 24 hours the action seemed to have been completed and all of the air to have been removed from the pores since no further increase was noted at the end of 48 and 72 hours.

Experiment (b)—As the greatest change took place during the first two hours, other experiments were conducted to determine the period of change. Three lumps were treated as before, but these were weighed at the end of 15, 30, 45, 60 and 120 minutes. The results are indicated graphically by the curve in Fig. 2, which represents the average values for

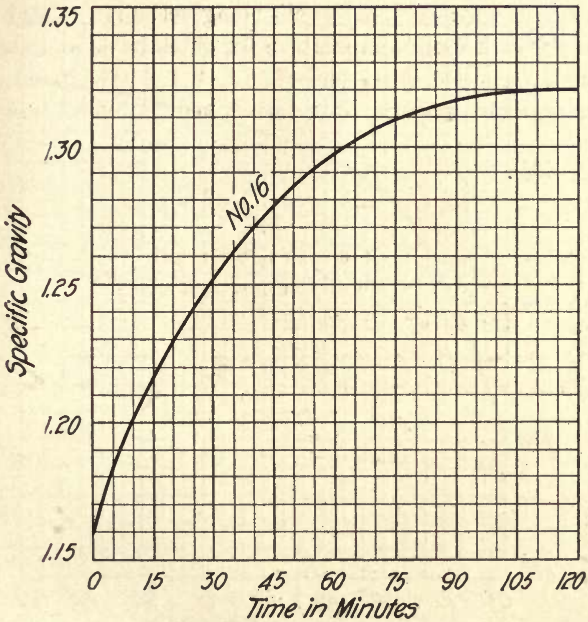

FIG. 2. GRAPH SHOWING CHANGE IN SPECIFIC GRAVITY OF COAL IMMERSED IN WATER AT ROOM TEMPERATURE, AVERAGE OF THREE TESTS.

the three lumps. These results show that the greater part of the change took place within one hour after immersion.

Other similar experiments were conducted in which two lumps of coal were used. Each lump was weighed in water at five-minute intervals for an hour, then at the end of two hours, and finally after twenty-four hours. The average results for the two lumps for the two-hour period are shown graphically by the curve in Fig. 3. There was no material change after two hours.

These two series of experiments, (a) and (b), indicate:

(1) That air-dry coal contains a considerable amount of air in its pores.

(2) That this air may be removed by immersing the coal in water, and that the specific gravity increases as the amount of included air decreases.

(3) That most of this air is displaced by water within about an hour after immersion.

(4) That this air is practically all removed at the end of twenty-four hours' immersion.

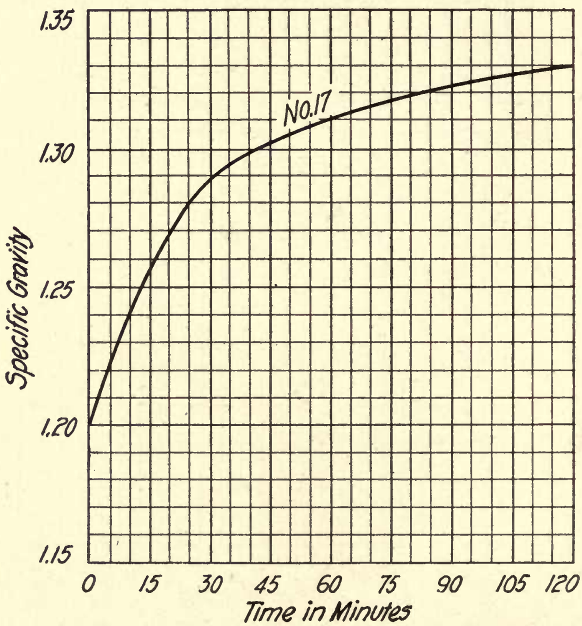

FIG. 3. GRAPH SHOWING CHANGE IN SPECIFIC GRAVITY OF COAL IMMERSED IN WATER AT ROOM TEMPERATURE, AVERAGE OF TWO TESTS.

In order to avoid delay in making specific gravity determinations it is desirable to remove the contained air as rapidly as possible. An increase in the rate at which the air is displaced may be accomplished in several ways:

(1) By increasing the temperature of the water in which the coal is immersed the density of the air in the pores of the coal is decreased, and consequently its tendency to rise is increased so that it will be displaced more rapidly by the water.

(2) By decreasing the pressure on the water and consequently on the air in the pores of the coal by placing it under a partial vacuum, the air expands and its density decreases, hence it is displaced more rapidly by the water.

(3) A combination of decrease of pressure and increase of temperature would have a double effect in increasing the rate at which the air is displaced by water. If this combination is effected by boiling under a vacuum, however, another factor must be considered; namely, the lowering of the boiling point of water with decrease in pressure. If the pressure is reduced to about 20 mm., water will boil at about room temperature, and the only effect accomplished is that due to decrease in pressure. It is probably that simple boiling under atmospheric pressure would have more effect.

Experiment (c)—To test the effect of boiling in hastening the displacement of the air, the specific gravity of each of a number of samples was determined, the weighed lumps of coal being boiled for about an hour and then weighed in water. The values are compared in Table 3 with the values obtained for samples of the same coal by immersing in water for twenty-four hours, each value representing the average of from six to eight determinations upon the same coal.

TABLE 3.

EFFECT OF BOILING UPON REMOVAL OF AIR.

Sample No.	Initial Sp. Gr.	After Boiling 1 Hour	Immersion for 24 Hours	Per Cent Air Removed by Boiling 1 Hour
9	1.26	1.34	1.34	100
15	1.19	1.31	1.32	92
42	1.28	1.32	1.32	100

Experiment (d)—In order to compare the relative effects of boiling and evacuating in hastening the displacement of the air the specific gravities of three samples were determined in duplicate, the weighed lumps of coal being evacuated in water for about an hour and then weighed in water. The evacuation was accomplished by means of an aspirator, and at the end of an hour the pressure was reduced to about 18 mm. so that the water was boiling at room temperature. The results are shown in Table 4, determinations being made in duplicate.

A comparison of the results given in Tables 3 and 4 shows that

TABLE 4.

EFFECT OF EVACUATION AND IMMERSION UPON REMOVAL OF AIR.

Sample No.	Initial Sp. Gr.	After Evacuating 1 Hour	Immersion for 24 Hours	Per Cent Air Removed by Evacuating
9	1.23	1.31	1.34	73
15	1.21	1.30	1.35	64
42	1.28	1.30	1.32	50

boiling the coal for one hour is much more effective than evacuating it for the same length of time.

2. *Specific Gravity of Fresh Coal.—Experiment (e)*—In order to study the specific gravity of fresh coal, samples were obtained from fresh faces in several mines in Vermilion county from Coal No. 7, and in Montgomery county, from Coal No. 6. Each sample contained about four pounds of coal, and was obtained by quartering down a large sample from a cut across the entire bed. The samples were sealed in air-tight cans and shipped to the laboratory in which the specific gravity of selected lumps was determined. Care was taken to select only those lumps which represented as nearly as possible the average of the entire sample. Lumps which contained pyrite or bands of shale were excluded, but both bright and dull coal were used in order to get a fair average.

The specific gravity of the fresh coal was determined with the Jolly Balance; the lumps were then boiled for an hour and the specific gravity again similarly determined. Instead of showing an increase in weight after boiling, as was characteristic of the air-dry coal previously tested, the lumps of fresh coal, with few exceptions, showed no increase (see Table 5). This indicates that the pores of fresh coal contain no air and are filled with moisture. Since this held true for coals which differed geologically and chemically, and since as-received analyses of coal always show a considerably higher content of moisture than air-dry or dry analyses, the evidence seems strong that Illinois coal in the fresh condition is saturated with moisture. It is probable that this moisture is held mechanically in the pores of the coal, since it is given off readily by drying upon exposure to the air, and since it can be taken up again in approximately the same amount if the coal is boiled in water for about one hour or simply immersed in water for a greater length of time, not exceeding twenty-four hours. If further investigation confirms these

results a method will have been established for comparing the specific gravities of different coals under standard conditions, in which the samples are boiled in water for an hour before determining the specific gravity. Although experiments (e) and (f) show the specific gravity thus determined to be slightly above the specific gravity of the fresh coal, it is much closer than the apparent specific gravity as usually obtained and near enough for all practical purposes.

TABLE 5.

SPECIFIC GRAVITY OF FRESH COAL.

Danville Field No. 7 Coal			Central Illinois Field No. 6 Coal		
Sample No.	Specific Gravity		Sample No.	Specific Gravity	
	Before Boiling	After Boiling		Before Boiling	After Boiling
125	1.24	1.24	138	1.31	1.31
126	1.29	1.29	139	1.27	1.27
127	1.29	1.29	140	1.29	1.29
128	1.29	1.30*	141	1.30	1.30
129	1.26	1.26	142	1.28	1.28
130	1.27	1.28*	144	1.28	1.28
131	1.28	1.28	145	1.28	1.28
132	1.32	1.32	146	1.28	1.28
133	1.26	1.26	147	1.27	1.27
134	1.29	1.29	148	1.32	1.32
135	1.32	1.32	149	1.28	1.29*
136	1.26	1.26	150	1.32	1.32
137	1.30	1.30	151	1.27	1.27
			152	1.29	1.30*
Average	1.28	1.28	153	1.29	1.29
			154	1.30	1.30
			155	1.31	1.31
			156	1.31	1.31
			157	1.31	1.31
			158	1.29	1.29
			159	1.31	1.31
			160	1.30	1.30
			161	1.30	1.30
			Average	1.29	1.29

*In one or two instances a slight increase in weight was noted, which may have been due to one or two causes; either the sample was taken from a portion of the bed in which the coal was not perfectly fresh, or the lumps had been accidentally permitted to dry a trifle before being used.

3. *Comparison of Specific Gravity of Fresh and Dry Coal.*—In order to study the effect of drying upon the specific gravity, portions of a number of the samples of fresh coal were placed in shallow containers and allowed to dry exposed to the air of the laboratory. The pieces of coal ranged in size from ½ in. to 2 in. in diameter. The air of the laboratory was at a fairly constant temperature of about 24°C.

Experiment (f)—The samples of Vermilion county coal were allowed to dry for sixty days, and at the end of that time lumps were selected and their specific gravities determined. In Table 6 the values are compared with those obtained for the fresh coal. They show that upon drying, the apparent specific gravity of the coal decreased considerably, but that the specific gravity obtained after boiling the air-dried coal showed an increase over the fresh coal. This variation is probably due to loss of moisture during the drying.

TABLE 6.

COMPARISON OF THE SPECIFIC GRAVITY OF FRESH AND AIR-DRY COAL FROM VERMILION COUNTY.

Sample No.	Fresh		Air-Dry for 60 Days	
	Before Boiling*	After Boiling	Before Boiling*	After Boiling
125	1.24	1.24	1.16	1.26
126	1.29	1.29	1.18	1.33
127	1.29	1.29	1.22	1.32
128	1.29	1.30	1.20	1.32
129	1.26	1.26	1.19	1.29
130	1.27	1.28	1.18	1.29
131	1.28	1.28	1.18	1.29
132	1.32	1.32	1.22	1.36
133	1.26	1.26	1.16	1.29
134	1.29	1.29	1.19	1.31
135	1.32	1.32	1.18	1.37
136	1.26	1.26	1.16	1.28
137	1.30	1.30	1.19	1.34
Average	1.28	1.28	1.19	1.31

*These values represent the apparent specific gravity of the coal.

Experiment (g)—The samples of coal from Montgomery county were dried in the same manner as those from Vermilion county, but lumps were selected and their specific gravity determined at the end of four weeks, and again at the end of five weeks. Moisture determinations were made each time in order that the relation between the loss of moisture and the variations in specific gravity might be studied quantitatively. In Table 7 the values obtained are compared with those obtained for fresh coal.

These values show that, as in the case of the Vermilion county coal, the specific gravity of the air-dry coal before boiling (the apparent specific gravity) is less than that of the fresh coal; also, that the specific gravity after boiling is more than that of the fresh coal. In addition they show that the coal lost from 9 to 10 per cent of moisture during the drying.

This loss of moisture explains the high values obtained for the specific gravity after boiling because, although the loss of moisture causes a decrease in the weight in air, the weight in water is approximately the same, whether the coal is fresh or dry. To determine the latter point the following experiment was carried out:

Experiment (*h*)—A number of samples of fresh coal were selected and their specific gravities determined. These samples were put aside and allowed to dry in the air for sixty days, and at the end of that time their specific gravities were again determined, each lump being weighed in water before and after boiling. These weights, together with the corresponding specific gravities, are given in Table 8, which shows that the weight of the lumps in air decreased from 8 to 10 per cent after drying, while the weight of the lumps in water after boiling was approximately the same for the dry as for the fresh coal, the average difference for the thirteen samples being only 0.09. Thus the higher values for the specific gravity after boiling, given in Tables 6, 7, and 8, seem to be the natural consequence of the loss in moisture during the drying.

Table 7.

Comparison of the Specific Gravity and Moisture Content of Fresh and Air-Dry Coal From Montgomery County, Illinois.

Sample No.	Fresh Coal			Air-Dry Coal					
				Four Weeks			Five Weeks		
	Moisture Per Cent	Specific Gravity		Moisture Per Cent	Specific Gravity		Moisture Per Cent	Specific Gravity	
		Before Boiling	After Boiling		Before Boiling	After Boiling		Before Boiling	After Boiling
138	13.58	1.31	1.31	4.04	1.23	1.33	4.91	1.26	1.37
141	13.64	1.30	1.30	3.30	1.25	1.33	5.06	1.23	1.34
144	12.65	1.38	1.28	3.07	1.24	1.33	5.64	1.24	1.31
147	14.95	1.27	1.27	3.26	1.24	1.37	5.55	1.22	1.36
150	13.67	1.32	1.32	3.79	1.22	1.36	5.01	1.21	1.34
154	14.72	1.30	1.30	4.85	1.21	1.32	5.48	1.24	1.33
156	13.30	1.31	1.31	4.51	1.24	1.34	4.94	1.22	1.34
159	14.21	1.31	1.31	4.31	1.21	1.33	4.62	1.26	1.36
Average	13.84	1.30	1.30	3.89	1.23	1.34	4.90	1.24	1.34

The amount of moisture lost when fresh coal is exposed to the air probably depends upon (a) the original moisture content, (b) the degree of fineness of the coal, (c) the humidity of the air in which the coal is exposed, and (d) the length of time the coal is exposed to the air. Table

7 shows that the moisture content was higher after five weeks' exposure than after four weeks. This increase may have been due to the fact that the air was more humid when the latter determinations were made, for the initial moisture and degree of fineness were about the same for all samples and the moisture determinations were made in the same manner, but the moisture in the air was not determined.

It was shown in Tables 6 and 7 that the apparent specific gravity of the coal decreased as the coal dried out. This might be explained by the loss in weight of the lumps due to the loss of moisture. If a 25-gram

TABLE 8.

THE EFFECT OF DRYING UPON WEIGHT OF LUMPS OF COAL IN AIR AND IN WATER.

Sample No.	Fresh Coal			Dry Coal				
					Before Boiling		After Boiling	
	Weight in Air	Weight in Water	Specific Gravity	Weight in Air	Weight in Water	Specific Gravity	Weight in Water	Specific Gravity
125	16.53	3.18	1.24	15.00	1.97	1.15	3.08	1.26
126	20.23	4.57	1.29	18.51	2.95	1.18	4.53	1.33
127	19.12	4.32	1.29	17.76	3.16	1.22	4.35	1.32
128	21.92	5.03	1.30	20.08	3.32	1.20	4.87	1.32
129	15.13	3.09	1.26	13.80	2.10	1.18	2.95	1.28
130	20.27	4.40	1.28	18.55	2.78	1.18	4.15	1.29
131	25.20	5.59	1.28	23.06	3.62	1.18	5.20	1.29
132	29.61	7.04	1.32	28.56	4.85	1.20	7.08	1.33
133	20.51	4.22	1.26	18.72	2.58	1.16	4.25	1.29
134	25.91	5.76	1.29	23.61	3.69	1.19	5.57	1.31
135	14.98	3.60	1.32	13.32	2.08	1.18	3.60	1.37
136	25.92	5.38	1.26	23.64	3.26	1.16	5.24	1.28
137	27.87	6.39	1.30	24.92	4.10	1.19	6.42	1.34
Average	21.78	4.81	1.28	19.96	3.11	1.18	4.72	1.31

lump of fresh coal weighs 5 grams in water, it displaces 25—5—20 grams of water, and its specific gravity is equal to $\frac{25}{25-5} = \frac{25}{20} = 1.25$.

If the same lump loses 10 per cent of its moisture when it dries out, its weight in air is decreased by 10 per cent and is then equal to 25 (1—0.10) = 22.5 grams. In determining the apparent specific gravity the lump is weighed before any water can enter its pores, so that it displaces the

same amount of water as before, or 20 grams. Then, its apparent specific gravity is equal to

$$\frac{22.5}{20} = 1.125. \quad \text{Of, if}$$

$W =$ weight of fresh coal in air,
$w =$ weight of fresh coal in water,
$S_f =$ specific gravity of fresh coal,
$L =$ per cent loss of moisture during drying, and
$S_a =$ apparent specific gravity of air-dry coal,

$$\text{then } S_f = \frac{W}{W - w}, \text{ and } S_a = \frac{W - WL}{(W - L) - (w - L)} = \frac{W(1 - L)}{W - w}$$

$$= S_f\ (1 - L)\ \left(\text{since } S_f = \frac{W}{W - w}\right).$$

Therefore, if the loss in moisture alone causes the decrease in the apparent specific gravity, the value of the latter for air-dry coal can be easily calculated, knowing the loss of moisture and the specific gravity of the fresh coal. This is a simple relation and would prove of considerable practical value if it could be shown to accord with experimental facts. It does not seem to hold true, however, for the type of coal used in the present investigation. Values were calculated for a number of samples, according to the above formula, and compared by experiment; these are given in Table 9.

In every case except one (that of Sample 150), the calculated values are too low, or in other words the apparent specific gravity did not decrease with loss of moisture as much as it should if loss of moisture were the only factor affecting this decrease in specific gravity. Evidently, for this type of coal (Illinois bituminous) some other factor, or factors, partially counteracted the effect of drying on the apparent specific gravity.

One factor which might have an appreciable effect in this way is that of oxidation. A number of investigators have shown that if coal is exposed to the air for some time it absorbs oxygen, that oxidation takes place between the absorbed oxygen and some of the light hydrocarbons which are present in the coal, and that the oxidation is attended by an appreciable increase in weight. Sommermeier noted an increase in weight

from about 1 per cent to 2½ per cent for Illinois coals after from eight to thirteen months' exposure.* Parr states that one of the principal products of this oxidation is water, and that all coal samples prepared for laboratory work, even though kept in rubber-stoppered bottles, change in moisture content, so that after only a few weeks the moisture in the coal under these conditions will increase, sometimes to an extent of 1 per cent or 1½ per cent.† Hundreds of determinations have been made in his laboratory showing such increase in moisture.

In whatever form the light hydrocarbons existed in the coal, it is safe to conclude that if they were replaced by an oxidation product, such

TABLE 9.

COMPARISON OF CALCULATED AND EXPERIMENTAL VALUES OF THE APPARENT SPECIFIC GRAVITY.

Sample No.	Fresh Coal		Coal Dried 4 Weeks			Coal Dried 5 Weeks		
	Per Cent Moisture	Specific Gravity	Per Cent Moisture	Apparent Sp. Gr. Calculated	Apparent Sp. Gr. Experiment	Per Cent Moisture	Apparent Sp. Gr. Calculated	Apparent Sp. Gr. Experiment
138	13.58	1.31	4.04	1.18	1.23	4.91	1.20	1.26
141	13.64	1.30	3.30	1.16	1.25	5.06	1.19	1.23
144	12.65	1.28	3.07	1.16	1.24	5.64	1.18	1.24
147	14.95	1.27	3.26	1.12	1.24	5.55	1.15	1.22
150	13.67	1.32	3.79	1.19	1.22	5.01	1.20	1.15
154	14.72	1.30	4.85	1.16	1.21	5.48	1.17	1.24
156	13.30	1.31	4.51	1.19	1.24	4.94	1.20	1.22
159	14.21	1.31	4.31	1.18	1.21	4.62	1.19	1.26
	Average	1.30	Average	1.17	1.23	Average	1.19	1.23

as water, an increase in the specific gravity, as determined by the boiling or soaking process, would result.

4. *Special Method of Determining Fresh Specific Gravity.*—It has been shown that, in the case of the coal under consideration, the calculation of the specific gravity of coal in the fresh condition, based upon tests in the dry condition, or vice versa, is not feasible. It is not always possible to obtain fresh coal for specific gravity determinations, since such coal must be taken directly from unaltered portions of the coal bed. It would, however, be of considerable advantage to have some method of finding a value which would represent the specific gravity of coal in the

*Bul. 323, U. S. G. S., p. 22.

†Oral communication.

fresh condition, when only the air-dry coal or commercially-dry coal is available.

The experiments described previously suggested a simple method of determining the specific gravity of the fresh coal from samples of air-dry or commercial coal, such as can be easily obtained. It has been shown that if lumps of coal are soaked in water for about twenty-four hours they reabsorb about the same amount of water as they lose in drying, and their weight in water is nearly the same as when the coal was fresh. If the weight in water is the same as that of the fresh coal, the weight in air ought to be the same, if care is taken not to weigh any extra water which may cling to the surface of the coal. If both the weight in air and in water are the same for saturated dry coal as for fresh coal, then the specific gravities must be the same.

Experiment (i)—In order to ascertain whether the assumption made

TABLE 10.

COMPARISON OF FRESH SPECIFIC GRAVITY DETERMINED ON BOTH FRESH AND ON AIR-DRY COAL SATURATED.

Sample No.	Specific Gravity	
	Fresh Coal	Air-Dry Coal Saturated
140	1.29	1.30
141	1.30	1.30
144	1.28	1.29
147	1.27	1.29
150	1.32	1.32
154	1.30	1.31
156	1.31	1.31
161	1.30	1.32

in the preceding paragraph is true, eight or ten lumps of each of eight samples of dry coal were soaked in water until they were saturated (about twenty-four hours). At the end of that time they were taken out, the water adhering to the surface of each lump was removed with a cloth or with filter paper, and the lumps were exposed to the air for about five minutes. They were then weighed in air and in water and their specific gravity calculated. The values obtained in this way, as given in Table 10, checked closely with the values of the specific gravity previously determined for the same samples when the coal was fresh. Hence, if only air-dry coal is available, by this method the specific gravity of fresh coal can be determined to a degree of accuracy sufficient for all practical pur-

poses, and the extent to which the coal has dried out will probably not affect the accuracy of the results.

To determine whether or not the amount of water evaporated from the coal by leaving it exposed to the air before weighing would change the weight of the lump enough to affect its specific gravity appreciably, the following experiment was carried out:

Experiment (j)—Eight lumps of air-dry coal were soaked in water until they were saturated, and then were weighed in water. Each lump was dried only superficially, and was weighed before there was any chance for the moisture to evaporate to any extent. Then, each lump was allowed to dry for fifteen minutes, which gave ample opportunity for some of the moisture to evaporate, and was again weighed. Another weighing was made after the coal had dried for an hour. As shown by Table 11 there was no change in the specific gravity after drying for fifteen minutes, and in only one instance was there a change after an hour, and that was very small. Since in the general method outlined above the lumps were allowed to dry for only five minutes, it is evident that no error is introduced by water adhering to the surface of the lumps.

TABLE 11.

EFFECT UPON SPECIFIC GRAVITY OF DRYING MOIST LUMPS BEFORE WEIGHING.

Sample No.	Specific Gravity		
	At Initial Weighing	At End of 15 Minutes	At End of 1 Hour
1	1.33	1.33	1.33
2	1.35	1.35	1.36
3	1.30	1.30	1.30
4	1.30	1.30	1.30
5	1.35	1.35	1.35
6	1.29	1.29	1.29
7	1.30	1.30	1.30
8	1.29	1.29	1.29

5. *Specific Gravity of Bright and Dull Coal.*—Illinois coal is usually banded in appearance, consisting of alternate bright and dull layers. The coal material consists of organic and mineral matter, and the banded appearance is due to the alternation of layers that are an admixture of the organic and mineral matter in different proportions and in different ways.

The organic matter of coal may be divided into three substances:¶ (1) lignitoid or glance coal, (2) canneloid or matt coal, and (3) mother of coal or mineral charcoal. Jeffrey calls the bright layers "lignitoid coal," and considers that it is derived from woody material. He calls the dull layers "canneloid coal," and considers that it is derived largely from plant spores, together with fragments of leaves, stems, etc. Thiessen § speaks of the dull material as "debris," but his conclusions are similar to those of Jeffrey. These conclusions are based upon the results of refined microscopic study of thin sections of coal from which all mineral matter had been removed.

TABLE 12.

SPECIFIC GRAVITY OF BRIGHT AND DULL COAL.

Sample No.	Apparent Specific Gravity		Fresh Specific Gravity	
	Bright Coal	Dull Coal	Bright Coal	Dull Coal
401 a	1.26	1.31‡	1.29	1.35‡
b	1.27	1.31‡	1.29	1.35‡
c	....	1.56†	....	1.57†
402 a	1.30	1.42‡	1.33	1.45‡
b	1.26	1.42‡	1.29	1.45‡
c	1.25	.....	1.29	.....
403 a	1.15	1.26*	1.26	1.37*
b	1.19	1.22*	1.26	1.35*
c	1.21	1.25*	1.26	1.35*
d	....	1.26*	....	1.37*
e	....	1.19*	....	1.32*
404 a	1.22	1.39*	1.31	1.48*
b	1.19	1.24*	1.26	1.31*
405 a	1.26	1.65*	1.28	1.67*
b	1.26	1.57*	1.29	1.59*
c	1.26	.....	1.28	.....
d	1.26	.....	1.28	.....

* = Banded.
† = Shaly.
‡ = Homogeneous.

Coal which appears dull may, then, be dull because it is composed of the material referred to as canneloid coal, or as mother of coal. It may, however, appear dull because of the admixture of mineral matter, such as mud or shaly material, present either in intimate mixture or as thin layers or partings between layers of organic material. It is probable that the dull appearance of many Illinois coals is due in part to this admixture of shaly material, as well as to the presence of the canneloid

¶E. C. Jeffrey, Economic Geology, Vol. 9, No. 8, p. 741.
§R. Thiessen, Bul. No. 38, U. S. Bureau of Mines.

type of coal. The difference in specific gravity between bright and dull coal seems to indicate that this is true.

Experiment (k)—Specimens of bright and dull coal were selected at random from the same sample and their specific gravity determined. The bright specimens in each case appeared to be homogeneous with little or no admixture of dull or shaly material. The dull specimens in some cases appeared homogeneous, without distinct bright or shaly material; in other cases they were distinctly shaly; and in still other cases they appeared banded bright and dull, with a predominance of dull bands. In

TABLE 13.

RELATION OF SPECIFIC GRAVITY OF BRIGHT AND DULL COAL TO ASH AND MOISTURE CONTENT.

Sample No.		Fresh Sp. Gr.	Moisture (Air-dry)	Ash	Dry Ash
401	BC	1.29	5.83	2.77	2.95
	DC	1.35	3.82	37.15	38.62
	DS	1.57	2.06	36.65	37.42
402	BC	1.30	6.92	2.94	3.16
	DC	1.45	2.96	42.72	44.02
403	BC	1.26	5.79	2.70	2.86
	DB	1.35	2.99	11.32	11.67
404	BB	1.28	6.58	4.21	4.51
	DB	1.40	3.71	34.36	35.69
405	BC	1.28	5.96	2.65	2.82
	DB	1.63	2.78	27.51	28.29

BC = Bright, very clean coal.
DC = Dull coal, bony, but not distinctly shaly.
BB = Bright and banded in appearance with a few dull streaks.
DB = Dull and banded, with a few bright streaks.
DS = Dull and distinctly shaly.

every case the specific gravity of the dull coal was greater than that of the bright coal from the same sample. The results are shown in Table 12.

In order to study the effect of admixture of impurities in dull coal and, if possible, the relation between specific gravity and ash and moisture contents, determinations were made of the ash and moisture contents of the bright and dull lumps, of which the specific gravity was determined. The results of this study are shown in Table 13. The most important facts brought out by these data are:

(1) In every case the specific gravity of the dull coal was decidedly greater than that of the bright.

(2) The ash content of the dull coal was much greater than that of the bright coal.

(3) The moisture content of the bright coal was in every case greater than that of the dull coal, although all lumps had been subjected to about the same conditions.

These facts lead to the following conclusions:

(1) Admixture of impurities, especially of shaly material, is a common feature in the dull portions of Illinois coal.

(2) Bright coal is probably considerably more porous than dull coal, since in the experiments made it showed a uniformly higher moisture content, in spite of the fact that it had been exposed to the air for the same length of time and under the same conditions as the dull coal. This is probably due to the admixture of shale in the dull coal, since shale is known to have a very low porosity.

V. Field Study of Specific Gravity.

6. *Fresh Coal from Vermilion County.*—In order to determine the fresh specific gravity of Illinois coal on a more extensive scale, field trips were made to the Vermilion county coal field, near Danville, Illinois, and with a complete improved Jolly Balance equipment determinations of the fresh specific gravity were made at the mines, while the coal collected was perfectly fresh lumps ½ to 1 inch in diameter, being used in making the determinations.

Two coal beds of workable thickness, No. 6 and No. 7, of the Illinois State Geological Survey correlation, are mined in the district, and samples were collected from both. The coal is composed of alternate bright and dull bands of variable thickness, with numerous thin partings of shale, mineral charcoal or mother of coal, and pyrite. Some of these partings are quite persistent and divide the coal bed into benches which are known locally as the "top coal," "blacksmith coal," "bottom coal," etc.

Experiment (1)—In order to obtain a value for the specific gravity that would represent the whole coal bed with reasonable accuracy, it was found advisable to sample each bench, instead of sampling the bed as a whole; that is, lumps were collected from each bench appearing persistent over a considerable area. A value was thus obtained which was representative of the particular bench from which the sample was taken,

but not necessarily of the whole bed. The average value for the whole bed was found by multiplying the value for each bench by the thickness of that bench in inches, and dividing by the total thickness of the bed.

TABLE 14.

SPECIFIC GRAVITY OF COAL NO. 7 BY BENCHES.

Sample No.	Bench No. 1	Bench No. 2	Bench No. 3	Bench No. 4
230	1.24	1.33	1.25	1.29
231	1.24	1.29	1.26	1.29
232	1.24	1.28	1.27	1.26
233	1.24	1.32	1.26	1.28
234	1.24	1.30	1.26	1.35
235	1.24	1.27	1.27	1.28
236	1.24	....	1.27	1.31
237	1.24	....	1.27	1.31
238	1.24	1.31	1.28	1.32
239	1.25	1.34	1.26	1.30
240	1.25	1.31	1.25	1.28
241	1.25	1.27	1.25	1.34
242	1.24	1.26	1.26	1.30
243	1.25	1.30	1.25	1.36
244	1.23	1.30	1.26	....
245	1.25	....	1.28	....
246	1.24	....	1.31	1.29
247	1.26	1.26	1.26	1.34
248	1.27	1.25	1.28	1.27
249	1.26	1.32	1.25	1.26
250	1.26	1.25	1.26	1.31
251	1.28	1.31	1.33	1.27
252	1.25	1.28	1.26	1.26
253	1.28	1.30	1.29	1.27
254	1.26	1.31	1.30	....
255	1.27	1.32	1.27	1.30
256	1.29	1.28	1.26	1.29
257	1.25	1.27	1.28	....
258	1.22	1.29	1.27	....
259	1.29	1.29	1.27	....
260	1.26	1.27	1.26	....
261	1.25	1.26	1.28	....
262	1.27	1.29	1.27	....
263	1.27	1.27	1.27	....
264	1.27	1.31	1.27	....
265	1.30	1.26	....	....
Average	1.26	1.29	1.27	1.30

Bench No. 1 = Top Coal.
Bench No. 2 = Middle Bench.
Bench No. 3 = "Blacksmith Coal" (local name).
Bench No. 4 = Bottom Coal.

A large number of lumps were selected from different points along each bench and at a number of localities in the district, and the specific gravity of each of these lumps was determined (see Table 14). The coal from different benches showed an appreciable difference in specific gravity, although the value from each bench was fairly constant.

Samples from different benches were obtained from thirteen different mines in the district, and the specific gravities determined imme-

diately by means of the portable Jolly Balance. The average value of each bench and for the entire bed was calculated for each sample by the method described, and the results for the bed are given in Table 15.

TABLE 15.

FRESH SPECIFIC GRAVITY OF DANVILLE COAL.

Coal No. 7		Coal No. 6	
Sample No.	Specific Gravity	Sample No.	Specific Gravity
201	1.27	207	1.29
202	1.29	208	1.28
203	1.27	209	1.29
204	1.29	210	1.27
205	1.29	211	1.27
206	1.27	212	1.28
213	1.27		
214	1.28	Average	1.28
215	1.29		
216	1.28		
217	1.28		
218	1.28		
219	2.26		
220	1.27		
221	1.27		
222	1.27		
223	1.28		
225	1.28		
226	1.29		
227	1.29		
228	1.28		
229	1.29		
230	1.29		
231	1.28		
232	1.28		
233	1.27		
Average	1.27		

7. *Coal From Other Districts.*—It was not found possible to collect samples of fresh coal from various parts of the state; therefore, in order to cover the ground thoroughly, samples of coal in varying stages of dryness were obtained from practically every district in the state.

The apparent specific gravity of each of these samples was determined by the Jolly Balance method. The values obtained for the different samples vary considerably, probably due to the difference in the length of time which elapsed between the mining of the coal and determination of its specific gravity. Also, the fresh specific gravity of each of these samples was determined by the approximate method described on pages 20 and 21, and the values obtained are given in Table 16.

Table 16.

Specific Gravity of Various Illinois Coals.

Sample No.	County	Coal Bed No.	Specific Gravity Apparent	Specific Gravity Fresh*	County Average Fresh Spec. Grav.*
301	Christian	6	1.24	1.30	
302	"	6	1.21	1.29	
303	"	6	1.24	1.34	
304	"	6	1.20	1.29	1.31—Christian
305	Franklin	6	1.25	1.30	
306	"	6	1.22	1.30	
307	"	6	1.26	1.30	
308	"	6	1.28	1.31	1.30—Franklin
309	Grundy	2	1.23	1.34	
310	"	2	1.24	1.34	
311	"	2	1.19	1.35	
312	"	2	1.18	1.29	1.33—Grundy
313	Jackson	2	1.26	1.31	
314	"	2	1.28	1.32	
315	"	2	1.27	1.34	
316	"	2	1.25	1.29	1.32—Jackson
317	La Salle	2	1.14	1.26	
318	"	2	1.21	1.32	
319	"	2	1.12	1.26	
320	"	2	1.17	1.28	
321	"	2	1.12	1.29	
322	"	2	1.13	1.28	
323	"	2	1.17	1.30	
324	"	2	1.16	1.29	1.28—La Salle
325	Logan	5	1.21	1.33	
326	"	5	1.18	1.30	
327	"	5	1.20	1.32	
328	"	5	1.17	1.28	1.31—Logan
329	Madison	6	1.22	1.28	
330	"	6	1.25	1.32	
331	"	6	1.22	1.29	1.30—Madison
332	Marshall	2	1.23	1.29	
333	"	2	1.18	1.27	
334	"	2	1.16	1.29	
335	"	2	1.17	1.28	1.28—Marshall
336	Mercer	1	1.23	1.29	
337	"	1	1.21	1.30	
338	"	1	1.22	1.31	
339	"	1	1.22	1.30	1.30—Mercer
340	Montgomery	6	1.25	1.31	
341	"	6	1.28	1.33	
342	"	6	1.29	1.29	
343	"	6	1.25	1.30	
344	"	6	1.24	1.29	
345	"	6	1.15	1.29	
346	"	6	1.19	1.30	
347	"	6	1.17	1.28	
348	"	6	1.15	1.30	
349	"	6	1.20	1.29	
350	"	6	1.19	1.31	
351	"	6	1.20	1.28	
352	"	6	1.22	1.29	
353	"	6	1.24	1.30	1.30—Montgomery
354	Perry	6	1.29	1.34	
355	"	6	1.26	1.31	
356	"	6	1.27	1.32	
357	"	6	1.24	1.35	1.33—Perry
358	Sangamon	5	1.08	1.27	
359	"	5	1.20	1.30	
360	"	5	1.14	1.28	
361	"	5	1.18	1.26	
362	"	5	1.17	1.30	
363	"	5	1.21	1.32	
364	"	5	1.20	1.30	
365	"	5	1.20	1.29	
366	"	5	1.22	1.31	
367	"	5	1.23	1.34	
368	"	5	1.21	1.30	1.30—Sangamon
369	Williamson	6	1.25	1.29	
370	"	6	1.29	1.33	
371	"	6	1.27	1.30	
372	"	6	1.29	1.32	1.31—Williamson

*Fresh specific gravity as determined on dry coal by the approximate method described on page 20.

VI. Practical Uses of the Specific Gravity of Coal.

There are several practical uses to which a knowledge of the specific gravity of coal may be applied, chief among which are the following:

(1) The calculation of the tonnage of coal in the ground over a given area.

(2) The calculation of the tonnage of quantities of broken coal, such as the coal stored in large bins or in stock piles.

(3) The comparison of coals by the rapid estimation of the ash and moisture content.

(4) The determination of the adaptability of coal to the removal of its impurities by washing processes.

8. *Tonnage of Coal in the Ground.*—It is often desirable to estimate the number of tons of coal in a given area underlaid by coal beds of a known or to be determined thickness. The volume of solid coal can be easily calculated, knowing the thickness of the beds and the area they cover; and the tonnage may then be found by multiplying the volume in cubic feet by the weight per cubic foot, and dividing by 2,000.

$$\text{Tonnage} = \frac{V \times W}{2{,}000}, \text{ in which}$$

V = volume in cubic feet, and
W = weight per cubic foot.

Since the weight per cubic foot of coal is equal to the specific gravity of the coal multiplied by the weight of a cubic foot of water (62.5 pounds), the formula becomes

$$\text{Tonnage} = \frac{62.5\, V S}{2{,}000} \quad (S = \text{specific gravity}).$$

It is necessary to know the specific gravity of the coal with reasonable accuracy if the estimate of tonnage is to have any value. An error of only a small amount in the specific gravity might cause the amount of coal recovered from a given area to fall millions of tons short of the estimated recovery. This fact was recognized by the Commission appointed to investigate the waste in coal mining in Pennsylvania in 1890. This Commission in its report stated that " . . . a variation of 1 per cent

in the specific gravity would reduce the total number of tons of coal in the ground 195,000,000."*

The importance of selecting the proper value for the specific gravity is evident when it is remembered that the specific gravity of any coal may be represented by a number of widely differing values, each perfectly correct for the condition which it represents. For example, the apparent specific gravity of a fresh coal may be 1.33, while after the coal has dried out it may be only 1.20. This difference of 0.13 in the specific gravity makes a difference of about 1,020 tons per acre for a bed of coal six feet thick, or over 650,000 tons for an area of only one square mile. This difference is far too great to be neglected, and it is therefore necessary to select the proper value for the specific gravity.

In selecting this value it should be remembered that the fresh specific gravity represents the condition in which the coal exists in the ground; the apparent specific gravity represents any condition of the coal at any stage in the drying process; while the dry and unit values represent only theoretical conditions that are never attained practically, and therefore, can be neglected in this connection.

The most practical value for use in the calculation of tonnage in the ground is one that represents the condition in which the coal exists when it is marketed, since the calculated weight will correspond to the weight upon which the price received for the coal is based. In the state of Illinois, coal that is marketed is usually settled for on the basis of weights at the mine. The coal is weighed as soon as it is placed in the railroad car ready for shipment. Only a short time elapses between the mining of the coal and weighing it, and therefore, the coal when weighed is practically fresh. It is not exposed to the air long enough after being mined to lose sufficient moisture to affect its weight appreciably. Since the coal is sold on a practically fresh basis, all calculations of tonnage in the ground should be based upon the fresh specific gravity of the coal.

9. *Tonnage of Broken Coal.*—In calculating the tonnage of a known volume of broken coal it is necessary to know not only the specific gravity of the coal, but also the amount of void spaces, or the amount of increased volume occupied by the coal when it is broken. For bituminous coal, such as that found in Illinois, this increase in volume probably varies from 60 per cent for large sizes to about 80 per cent for small sizes. Assuming

*Report of Penn. Coal Waste Commission, p. 11, 1893.

that the coal in question is in small sizes, the tonnage can be calculated by the formula:

$$\text{Tonnage} = \frac{62.5\ V S}{1.80}, \text{ in which}$$

V = volume in cubic feet, and
S = specific gravity.

Again, it is necessary to know which value of the specific gravity to use. In such a case, the manner in which the coal has been stored will affect its moisture content and consequently its specific gravity. Three cases should be considered; (a) when the coal has been stored under water, (b) when it has been stored in a tight bin, and (c) when it has been stored in an exposed stock pile.

(a) *Under Water Storage.*—Coal that is stored under water undergoes practically no deterioration, and its condition is practically the same after a long period of time as when freshly mined. Its specific gravity should not change, and consequently in calculating the tonnage of a given volume of coal stored under water the fresh value of the specific gravity should be used.

(b) *Closed Bin Storage.*—Coal that is stored in a closed bin should lose its moisture very slowly, but after a considerable length of time, for instance, several months or years, a large proportion of its contained moisture would probably be lost, especially if the coal were handled much during the process of transferring it to the bin. Under such conditions it would probably be necessary to obtain samples of the coal and actually determine its apparent specific gravity in order to obtain a reliable value upon which to base any calculations of tonnage.

(c) *Storage in Exposed Piles.*—Coal that is stored in exposed piles will lose moisture in dry weather and gain moisture in wet weather, and its specific gravity will vary accordingly. It is probable also that the specific gravity will not be the same on the surface of the pile as in the center or at the base, because evaporation of the moisture takes place more rapidly at the exterior. Under such conditions it would be almost impossible to estimate with any degree of precision the average specific gravity of the coal from any known values. Samples should be selected from different depths in the pile and the apparent specific gravity determined. On such an average value the estimate of tonnage should be based.

10. *Comparison of Coals.*—If the specific gravity of two coals of the same type and of the same moisture content, such as two bituminous coals from different parts of the same bed or even from different beds are compared, it is probable that the one having the higher specific gravity has also the higher ash content. They can be more conveniently compared if the moisture is entirely eliminated by calculating the dry specific gravity. By comparing the dry specific gravities of different coals of the same type a great deal might be learned about the other properties of the coal, especially the ash content. Since the heat value varies inversely as the ash content for a given coal, some idea might also be obtained as to the relative heat values of the two coals. Such a comparison could not be made between two types of coal such as a bituminous and an anthracite, or a bituminous and a lignite, but for the same types of coal valuable comparisons could be made. By eliminating all the impurities and using unit value of the specific gravity it might even be possible to draw valuable conclusions as to the relative heat values of different coals. Such a possibility is only suggested, but it may be worth further consideration.

11. *Specific Gravity and Coal Washing.*—Before an attempt is made to remove the impurities from coal by washing, the properties of both the coal and its impurities should be investigated to determine whether the coal is adaptable to washing, and which sizes give the best results. The common method of testing is the "float and sink" test, by means of which the impurities are removed from the crushed coal by immersing it in a heavy solution, such as a solution of calcium chloride or of zinc chloride, in which the impurities sink and the clean coal floats and can be skimmed away. The object of washing the coal is twofold; first, to reduce the ash below an arbitrary maximum, which depends upon the purposes for which the product is to be used, and secondly, to reduce the sulphur content to a minimum, especially if the product is to be utilized in manufacturing metallurgical coke. By testing with solutions of different specific gravity, one can be selected which will separate float coal with a little less than the maximum allowable ash. If the sulphur in the float coal has at the same time been reduced to a minimum, the coal is suitable for the manufacture of metallurgical coke, otherwise it is not. However clean the float coal may be, the sink material must contain only a small amount of coal if the separation is to be a commercial success. If the sink contains much coal the loss in the tailings will reduce the profits realized by the increased price of the clean coal until the washing is no longer economical. The lighter the coal and the heavier

the impurities, the cleaner will be the separation. If float and sink tests are carefully made by a standard method of procedure they give valuable comparative data.

Specific gravity tests may be used to advantage in determining the adaptability of coal to washing. They may be made either on average samples from the float coal and the impurities derived from float and sink tests, or they may be made directly upon the coal and upon the shale, which constitutes its chief impurity. All washing methods for the separation of coal from its impurities depend upon differences in specific gravity. The trough, washers, and the grading boxes depend upon the free settling ratio,* and the tub washers, jigs, and bumping tables upon the hindered settling ratio between the coal and its impurities.

Whether the washing takes place under free or hindered settling conditions, the greater the settling ratio the greater will be the range of sizes allowable in the coal and the cleaner will be the separation for a given size.

It has been shown that the apparent specific gravity of the coal itself decreases as the coal dries out. Values as low as 1.12 were obtained for very dry coal by the author, and values of 1.18 or 1.20 are quite common; whereas the apparent specific gravity of the same coal when fresh is about 1.30 or even more. As the specific gravity of the coal decreases its hindered settling ratio increases and the coal becomes more suited to washing, provided the specific gravity of the impurities remains unchanged. Pyrite and shale, the chief impurities, with the exception of fire-clay, are practically nonporous, and their saturation or nonsaturation with water should not affect their specific gravity. Fire-clay breaks up upon coming into contact with water, and in washing operations it is carried away with the water and does not enter into the process, except perhaps to slightly increase the specific gravity of the water. One example will suffice to illustrate the effect upon the specific gravity of drying the coal. Assuming hindered conditions with a quicksand having a specific gravity of 1.10, with impurities having a specific gravity of 2.40 and with fresh coal having a specific gravity of 1.30, the settling ratio becomes:

$$\frac{D}{D'} = \frac{2.40 - 1.10}{1.30 - 1.10} = \frac{1.3}{0.2} = 6.5.$$

*For a discussion of free and hindered settling ratios, see Bul. No. 69, University of Illinois Engineering Experiment Station, "Coal Washing in Illinois," by F. C. Lincoln.

If the coal is air-dry, with a specific gravity of 1.20,

$$\frac{D}{D'} = \frac{2.40 - 1.10}{1.20 - 1.10} = \frac{1.3}{0.1} = 13.$$

The hindered settling ratio $\frac{D}{D'}$ for the air-dry coal is just twice that for the same coal when fresh, and theoretically the coal when air-dry can be washed with a range of sizes twice as great as when fresh; or with a much cleaner separation for the same range of sizes. Consequently from this viewpoint it would seem advisable:

(1) Not to wash fresh coal, in other words, not to wash coal at the mine; the time required to ship coal to a distant point permits a certain amount of drying to take place. If the question should come up as to whether one large washery should be established near the market and all coal shipped from a number of mines to it, or a number of washeries should be built at the different mines and the product shipped to the market, a consideration of the relation between moisture content and the cleanness of separation would favor the central washery plan.

(2) Not to feed wet coal to the jigs or to other washing machines. The coal should be as dry as possible when it reaches the medium in which the separation of clean coal and impurities takes place. When washing fine sizes of coal it may be necessary to feed it wet in order to keep the coal from matting and floating over the jigs without being wetted. In such cases the wetting should be delayed as long as possible so that the coal will not remain wet long before being fed to the jigs.

These conclusions are based upon theoretical considerations of the results of study of the specific gravity of coal, and have little practical bearing.

VII. Summary.

(1) In general, no fixed value, such as can be given for mineral substances of definite chemical composition, can be given for the specific gravity of coal. Different types of coal, such as anthracite and bituminous, have different specific gravities, and even coals of the same general type may have quite different specific gravities, due to differences in content of ash and moisture.

(2) Fresh coal of the Illinois type is probably saturated with moisture, most of which is held mechanically in the pores of the coal.

(3) The specific gravity of fresh coals of the same general types should be about constant if the content of ash is about the same. The specific gravity of coal in the fresh condition has been called the "fresh" specific gravity.

(4) If coal has dried to any extent its specific gravity will vary, depending upon the amount of moisture lost. As the moisture content decreases the specific gravity should decrease (the ash content remaining the same), but not necessarily in a direct ratio. The specific gravity uncorrected for moisture or ash content has been called the "apparent" specific gravity.

(5) By calculating values of specific gravity to exclude the effect of moisture, values may be obtained which have been called the "real" or "true" specific gravity, and which might well be called the "dry" specific gravity to correspond with analyses of coal which have been calculated to the "dry" or "moisture-free" basis. By excluding both ash and moisture, values might be obtained which could be referred to as the "unit" specific gravity, to correspond with the unit coal B. t. u of Parr.

(6) By saturating air-dry coal with moisture before determining its specific gravity, a value can be obtained which represents quite closely the "fresh" value of the specific gravity, or the specific gravity of the coal in its fresh condition.

(7) The fresh specific gravity of coal from different counties in Illinois was found to vary from 1.28 to 1.33, with an average of between 1.30 and 1.31. These values, excepting those for Vermilion and Montgomery counties, were obtained from air-dry coal by the approximate method described on page 20 of this bulletin.

(8) In computing tonnages it is suggested that (a) for coal in the ground, the fresh specific gravity is the proper value to use, (b) for broken coal stored under water, the fresh specific gravity should be used, and (c) for broken coal stored in bins or in open piles the apparent specific gravity should be found for the average condition of the coal at the time the computations are made, and that value used.

(9) In coal washing operations the coal theoretically should be as dry as feasible when fed to the washing machines, since the settling ratios are considerably greater for dry than for wet coal, and dry coal can consequently be washed more efficiently.

VIII. Appendix A.—Methods of Determining Specific Gravity of Coal.

12. *General Methods for Solids.*—A number of methods have been devised for determining the specific gravity of solids, involving various methods of procedure and requiring various kinds of apparatus. Most of these methods are too well known to need description. They are as follows:

(a) Hydrostatic Balance Method.
(b) Jolly Balance Method.
(c) Pycnometer Method.
(d) Heavy Solution Method.

A few modifications of the Hydrostatic and Jolly Balances have been devised which permit especially rapid manipulation, but since these are not particularly applicable to the determination of the specific gravity of coal, a mere reference to them will suffice.*

13. *Special Methods for Coal and Coke Determinations.*—A number of modifications of the general methods have been used for the determination of the specific gravity of coal.

(a) *Ordinary Pycnometer Method of the U. S. Bureau of Mines.*†—"To determine the true specific gravity of coal and coke substance, the procedure is as follows: Approximately 3.5 grams of the 60-mesh coal or coke is weighed and introduced into a 50-c.c. pycnometer with about 30 c.c. of distilled water. In order to avoid loss of particles of the sample during boiling, a one-bulb 6-inch drying tube, *a* (Fig. 4), is connected with the pycnometer by means of a small piece of pure gum tubing or a rubber cork, *c*. The other end of the drying tube is connected with the aspirator. Suction is applied and the contents of the flask are gently boiled on the water bath *d* under partial vacuum for three hours in order to expel all air from the sample. The pycnometer is then detached, almost filled with boiled and cooled water, allowed to cool to the temperature of the balance room, stoppered, and weighed. The temperature of the contents of the pycnometer is taken immediately after

*M. von Schwartz, "Two New Types of Balance for Density Determinations," Munich Centr. Min. Geol., 1913, 565-570.

*Franz Toula, "A Quick Working Hydrostatic Balance," Min. Pet. Mitth., 26, 233-237.

*A. H. Sabin, "A Specific Gravity Balance for Solids," Orig. Com. 8th Inter. Cong. Appl. Chem., I, 441-443.

*W. Bahrdt, "Measurement of the Density of Solid Bodies," Z. Physik Chem., Unterricht, 26, 6-7; Chem. Zentr., 1913, I, 1390.

†Technical Paper No. 8, U. S. Bureau of Mines, 1914, "Methods of Analyzing Coal and Coke," by F. M. Stanton and A. C. Fieldner.

weighing. Each pycnometer is accurately calibrated and a table is constructed giving its capacity in grams of water at different temperatures.

"The true specific gravity is determined by use of the following formula:

$$\text{True specific gravity} = \frac{W}{W-(W'-P)}, \text{ in which}$$

W = weight in grams of dry coke = weight in grams of sample minus its moisture content.

W' = weight in grams of pycnometer plus dry coke, plus water to fill.

P = weight in grams of pycnometer plus water to fill."

(b) *Special Method of the U. S. Bureau of Mines.**—"The Hogarth flask recommended by Blair† for the determination of the specific gravity

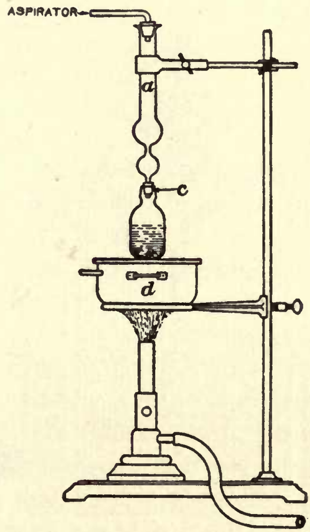

FIG. 4. ARRANGEMENT OF PYCNOMETER, U. S. BUREAU OF MINES.

of iron ores is more convenient and accurate for routine determinations of the specific gravity of coal or coke substances than is the ordinary pycnometer described in the preceding method. With the ordinary pycnometer it is difficult to insert the stopper without catching some floating particles between the stopper and neck.

"With the Hogarth flask is no such difficulty. The method of determination with the Hogarth flask is as follows:

*Technical Paper 8, U. S. Bureau of Mines, 1914.

†A. A. Blair, "The Chemical Analysis of Iron," 7th ed., 1908, p. 278.

"A 10-gram portion of the 60-mesh coal or coke is weighed and carefully introduced into the weighed flask (Fig. 5) with enough distilled water to fill the flask half full. The capacity of the Hogarth flasks obtained on the market varies from 100 to 125 c.c. The flask is then placed on a small electric hot plate in a 10-inch vacuum desiccator. The desiccator is evacuated by means of an aspirator or air pump. A current sufficient to keep the water boiling is passed through the hot plate. With an efficient vacuum pump all the air is expelled in 30 minutes. The flask is then removed from the desiccator, filled to the tubulure with recently boiled and cooled distilled water, and the stopper inserted. It is advisable to apply a thin film of vaseline to the stopper to prevent leakage.

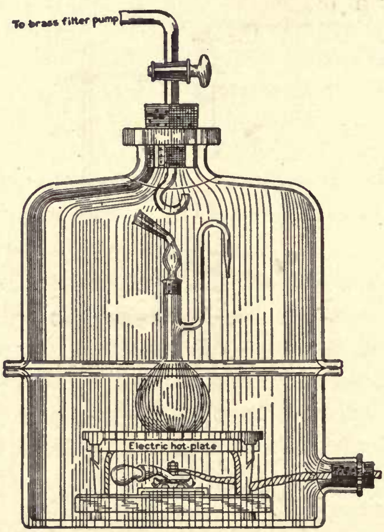

FIG. 5. HOGARTH FLASK METHOD.

"After the flask has been cooled to about 25° C. in a water thermostat, distilled water that has been cooled in the same thermostat is drawn through the tubulure until the water level is slightly above the mark on the capillary of the stopper. This may be done without removing the flask from the thermostat by inserting the end of the tubulure in a small beaker of water and applying a slight suction on the stopper. The flask should remain in the thermostat until the temperature of contents is exactly 25° C. The water level is adjusted to the mark on the capillary by touching a piece of filter paper to the end of the tubulure or by

drawing in a little water. The flask is then removed from the thermostat, wiped dry, and weighed. The true specific gravity is calculated as in the preceding method. (See formula, p. 39.) The value for P is obtained by filling the flask with boiled water, cooling, and weighing, as described above.

"By this method no difficulty is experienced in duplicating the figures for specific gravity to two decimal places."

(c) *Blakely and Chance Method.**—Messrs. Blakely and Chance, formerly chemists for the Philadelphia & Reading Coal & Iron Co., have described a method which they used for specific gravity determinations of coal. A representative sample of coal is reduced to 100 grams and placed in a 250 c.c. volumetric flask which has been previously calibrated. Then 100 c.c. of water is run in, suction applied, and the flask shaken. When the air-bubbles cease to rise, the suction is stopped and water run in from a burette up to the 250 c.c. mark.

$$\text{Specific gravity} = \frac{100}{V_0 - V_1}, \text{ in which}$$

V_0 = volume of the flask in cubic centimeters,

V_1 = number of cubic centimeters of water added after the evacuation.

By using a table of reciprocals calculation is facilitated, since the specific gravity equals 100 times the reciprocal of $V_0 - V_1$.

(d) *Brinsmaid's Method.*—Mr. William Brinsmaid developed in the laboratory of Professor S. W. Parr of the University of Illinois a volumetric method for specific gravity determinations. The apparatus consists of a pint fruit jar and an inverted glass funnel of the same diameter. (Fig. 6.) The rim of the funnel and the top of the jar are ground to insure a close joint. The center of the cap of the jar is cut out and the cap is placed over the funnel and screwed down to hold it firmly in place.

The volume of the two-part flask, as it may be considered, is determined by running in water from a burette up to a mark on the stem of the funnel. To make room for the lump of coal of which specific gravity is to be determined, enough water is removed through a pipette inserted in the funnel. The water is placed in a beaker and saved. Then the funnel is taken away and the lump of coal, previously weighed, is placed in the jar. The funnel is replaced, and water run in from the

*Mines and Minerals, Vol. 31, p. 499, March, 1911.

supply previously removed until the flask is again full up to the mark, the air-bubbles adhering to the coal being removed by shaking. Then the remaining water of the supply taken out at first is the water dis-

FIG. 6. PARR-BRINSMAID APPARATUS.

placed by the coal and has the same volume as the lump of coal. Its weight is determined from the following equation:

$$\text{Sp. Gr.} = \frac{Wc}{W}, \text{ in which}$$

Wc = weight of the coal,

W = weight of the water displaced.

(e) *Nicholson Hydrometer Method of the U. S. Bureau of Mines.**— "The apparatus used for determination of the apparent specific gravity (of both coal and coke) consists of a galvanized-iron cylinder (Fig. 7),

*Technical Paper No. 8, U. S. Bureau of Mines, 1914, p. 39.

which is filled with water to the water line, as indicated in the figure. In the cylinder is immersed a hydrometer made of brass. On the top of the hydrometer are two pans. The upper one is used for weights and the lower for the sample. Below the air buoy is a brass cage perforated with many holes to allow the air to escape when the instrument is immersed. The cage carries the sample when it is weighed under water. The method of determining the apparent specific gravity is as

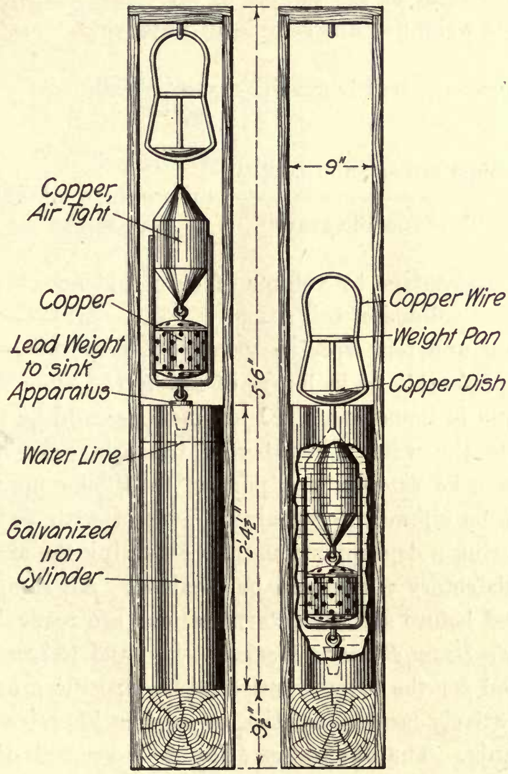

FIG. 7. NICHOLSON HYDROMETER FOR COAL AND COKE.

follows: Brass weights are placed on the upper pan until the hydrometer sinks to a mark on the stem between the copper pan and the buoy. The total weight required is recorded. The weights are removed, and about 500 grams of the sample in lump form (about 1½ to 2-inch cubes) are placed in the copper dish. Brass weights are then added until the hydrometer sinks to the mark on the stem. The difference in the weights

used gives the weight of the sample in air. The sample is then carefully transferred to the brass cage below the buoy. The weights on the upper pan are now adjusted until the instrument again sinks to the mark on the stem. The weight required to sink the hydrometer to the mark with no sample on the upper pan nor in the brass cage minus the weight required to sink it to the mark with the sample immersed in the cage equals the weight of the coke in water. Then:

If the weight of the sample in air $= x$
and the weight of the sample in water $= y$,

$$\text{the apparent specific gravity} = \frac{x}{x - y}$$

and

$$100\, x \frac{\text{apparent specific gravity}}{\text{True specific gravity}} = \text{percentage of volume of coke substance.}$$

Also,

100 — percentage by volume of coke substance = percentage by volume of cell space.

"In making apparent specific gravity determinations of coke the sample should preferably be in lumps of nearly the same size and shape. When the sample is immersed, the hydrometer should be moved rapidly up and down in the water a number of times in order to remove air bubbles. Since coke samples are porous, they take up water rapidly and should not be allowed to remain in contact with water more than five minutes during a determination. By observing the above-mentioned precautions satisfactory results can be obtained. All samples should be thoroughly dried before specific determinations are made."

(f) *Coxe's Beam Balance Method.*—In 1893 Eckley B. Coxe* described a method for the determination of the specific gravity of broken coal in comparatively large quantities, as used in his laboratory at Drifton, Pennsylvania. The apparatus (Fig. 8) consisted of a Fairbanks market beam scale and ordinary sheet-iron bucket, a cylindrical tin pan about 14 inches in diameter and 7 inches deep, and an ordinary washtub. The weighing beam was supported by a crane attached to a heavy post, and the apparatus was hung on the hook provided for suspending material to be weighed. A yoke was also attached to this hook, and the pan was suspended from it by means of wires and immersed in water in the tub. The coal of which the specific gravity was to be determined

*Presidential Address, New England Cotton Manufacturers' Association, 1893.

(about 20 lb.), after having been freed from dust and air-dried, was placed in the bucket, and its weight obtained by means of the poise and a suitable rider on the scale beam. It was then poured into the pan under water, and after it had been stirred in order to remove all air, the weight was obtained as before, and the specific gravity calculated in the usual manner.

(g) *Spring Balance Method.*—Mr. M. S. Hachita* has suggested the use of a large spring balance for obtaining the specific gravity of large sizes of coal. It could be used as well for large quantities of small

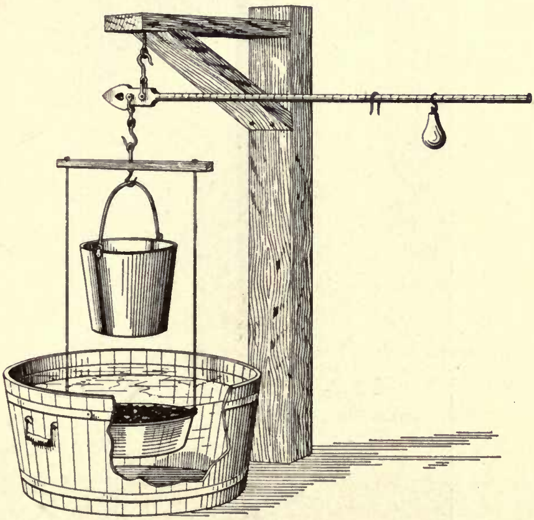

FIG. 8. COXE BEAM BALANCE.

sizes, and exactly in the manner described by Mr. Coxe for his beam balance.

(h) *Jolly Balance Method.*—The Jolly balance (Fig. 9) consists of a long delicate spiral spring suspended from an arm attached to a support S which can be moved vertically. This support is in the form of a tube graduated in centimeters and millimeters, and it moves inside of another tube to which a vernier is attached. Two pans are hung from the lower end of the spring, the lower one when in use being immersed in water up to a mark on the wire which holds it. The vertical support is placed so that its zero mark coincides with the zero of its vernier, then a movable mark on the stationary support is made to bisect the marks

*Mines and Minerals, Vol. 31, p. 499.

between the spring and the pans. These adjustments being made, the balance is ready for use.

A lump of coal is placed upon the upper pan, and the spring is stretched by raising the vertical support until a balance is reached. The amount the spring is stretched is read off by means of the vernier from the graduated scale of the vertical support. The lump of coal is then transferred to the lower pan and is immersed in water. The stretching

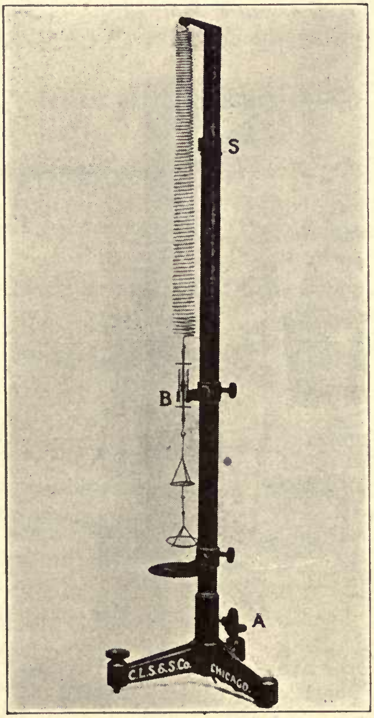

FIG. 9. JOLLY BALANCE.

of the spring is again recorded, and the specific gravity calculated by the formula:

$$\text{Sp. Gr.} = \frac{Wa}{Wa - A}, \text{ in which}$$

Wa = wt. in air, and

W = wt. in water.

Since the specific gravity is merely a ratio, the stretch of the spring may be used directly for the values Wa and W.

This method of determination may be used directly to obtain the apparent specific gravity. The manipulation of the balance is quite simple, and its operation is very rapid. If the actual weight in grams is desired, the balance may be calibrated with a set of weights. The calibration of the balance used is indicated in Table No. 17.

TABLE 17.
CALIBRATION OF SPRING BALANCE

Grams	Balance Reading	Value of One Space in Grams	Value of One Gram in Spaces
1	3.03	0.330	3.03
2	5.97	0.335	2.99
3	8.90	0.337	2.97
4	11.82	0.338	2.95
5	14.74	0.339	2.95
6	17.67	0.340	2.94
7	20.60	0.340	2.94
8	23.50	0.340	2.94
9	26.40	0.341	2.93
10	29.28	0.342	2.93
11	32.19	0.342	2.93
12	35.10	0.342	2.92
13	37.98	0.342	2.92
14	40.87	0.342	2.92
15	43.75	0.343	2.92

14. *Selection of a Method.*—A method for the determination of the specific gravity of coal should combine as far as practicable accuracy, rapidity of operation, and simplicity of apparatus, and any such method should be adapted to the particular type of work for which it is to be used. If especially accurate results are desired and if time is no object, a method similar to one of those in use at the U. S. Bureau of Mines for true specific gravity determinations might be employed. When rapidity is desired and approximate results are sufficient, as in most commercial work, a more rapid method is better. If the determinations must be made in the field and the apparatus moved about from place to place, a method should be employed which requires only a simple instrument, and one that is easily portable, such as a Nicholson hydrometer or one of the simpler balances. If large lumps or large quantities of material are handled, a method like Coxe's Beam Balance method, or the Spring Balance method would be suitable. If the lumps are of moderate sizes the Nicholson hydrometer, or a method such as that suggested by Prof. Parr would serve the purpose. If only small sizes of coal are available, a pycnometer method should be used for accurate determinations, and a method such as the Jolly Balance method for the less accurate work.

Since the pycnometer methods of the Bureau of Mines are somewhat complicated, the author tried a more simple pycnometer method for purposes of comparison with the Jolly Balance. The specific gravity of a number of samples of dry coal was determined in the following way:

Pycnometers having a volume of 10 c.c. were weighed full of water at room temperature, a portion of the water was removed, and a one-gram sample of 20-mesh coal was placed in each. They were again filled with water, stoppered, and boiled in a beaker of water for about an hour, in order to remove all air from the coal. After they had cooled to room temperature they were filled to the mark with water and weighed. The specific gravity was computed by the formula:

$$\text{Sp. Gr.} = \frac{Wc}{(Wc + W) - W'}, \text{ in which}$$

Wc = weight of coal in air,

W = weight of pycnometer when full of water,

W' = weight of pycnometer when containing coal and filled with water, and

$(Wc + W) - W'$ = weight of water displayed by the coal.

The calculations were simple, as $Wc = 1$, W is a constant, and the specific gravity is the reciprocal of a constant minus W'.

This method was found unsatisfactory. Fine material was easily lost during the process, and it was difficult to remove all the air from the coal.

For purposes of comparison with the pycnometer method just described, the specific gravity of the same samples of coal was determined by the standard Jolly Balance method, the lumps being boiled in water for one hour and then cooled to room temperature before being weighed in water. The values obtained by the two methods are given in Table 18, and an examination of these data shows that the pycnometer method gave lower values than the Jolly Balance method. Evidently, in the latter case all the air was not removed from the pores of the coal before it was weighed in water.

15. *Method Adopted.*—The Jolly Balance method was found to be much more satisfactory, and it was adopted as the method for obtaining the specific gravity determinations made in connection with the preparation of this bulletin. The apparatus is quite simple, it requires lumps of a convenient size and only a small sample of coal, is rapid in operation, only a few seconds being required to make a weighing, and is sufficiently accurate for ordinary work. The chief objection to it is

that the lumps used for the determination are selected arbitrarily, which makes possible the admission of personal errors, since the operator may reject portions of the sample which contain pyrite or shale partings, and select only lumps which represent the average of the sample. In the investigation here described lumps weighing from 5 to 20 grams were used.

16. *Selection of Coal Sample.*—The effect of ash upon the specific

TABLE 18.

COMPARISON OF JOLLY BALANCE AND PYCNOMETER METHODS.

Sample No.	Specific Gravity	
	Jolly Balance	Pycnometer
1	1.28	1.26
2	1.26	1.27
3	1.28	1.27
4	1.33	1.27
5	1.31	1.32
6	1.33	1.26
7	1.33	1.27
8	1.35	1.29
9	1.33	1.29
10	1.32	1.26
11	1.29	1.26
12	1.32	1.27
13	1.29	1.25
14	1.28	1.28
15	1.31	1.25
16	1.31	1.31
17	1.31	1.31
18	1.31	1.28
19	1.32	1.29
20	1.39	1.29
21	1.35	1.28
22	1.36	1.31
23	1.37	1.32
Average	1.32	1.28

gravity has long been recognized. Dull coal may have a higher ash content than bright, glossy coal, and consequently a higher specific gravity. This condition should be taken into consideration, and lumps should be selected so that the average result will represent dull and bright coal in their proper proportions in the sample. Results which show abnormally high values are probably due to the fact that certain lumps contain an abnormal amount of shale or pyrite, and such results should be rejected in the general average, unless a large number of lumps are averaged.

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